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Trampling *versus* cut marks on chemically altered surfaces: an experimental approach and archaeological application at the Barranc de la Boella site (la Canonja, Tarragona, Spain)

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ABSTRACT

Several studies have attempted to identify diagnostic criteria for distinguishing between evidence of trampling and cut marks, two common modifications at archaeological sites. These studies have brought to light, with relative precision, the features that identify and differentiate the two types of modifications. However, few studies differentiate these modifications after they have been affected by other factors. Chemical alteration, related to lixiviated sediments, is documented in a relatively high number of archaeological sites. Following the criteria established by Domínguez-Rodrigo et al. (2009), the aim of this paper is to know if diagnostic criteria that would allow modifications resulting from trampling to be differentiated from cut mark modifications are preserved, after undergoing chemical alterations. The results have been applied to unidentified marks located on faunal skeletal remains from the La Mina site, at the Barranc de la Boella (Tarragona, Spain), the surfaces of which have been heavily modified by the lixiviation of the sediments. The data suggest that chemically altered marks lose the diagnostic criteria necessary for correct identification. The unidentified marks discovered on remains from la Boella could not be verified as cut or trampling marks and therefore cannot be considered in future zooarchaeological and taphonomical studies.

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1. Introduction

Trampling is defined as the friction process occurring between sedimentary particles and bones caused by hominin and/or animal transit over the surface or by carnivore consumption, in addition to other processes. Trampling can cause modifications on the surfaces of archaeological bones, give rise to fractures and contribute to the dispersion of an assemblage.

Some researchers (Andrews and Cook, 1985; Fiorillo, 1991; Kos, 2003; Stuart and Larkin, 2010) have described the effects of trampling at archaeological sites. However, other studies have employed experimentation to make inferences about this phenomenon (Villa and Courtin, 1983; Gifford-González et al., 1985; Behrensmeyer et al., 1986; Olsen and Shipman, 1988; Nielsen, 1991; Holen, 2006; Blasco et al., 2008; Domínguez-Rodrigo et al., 2009; Eren et al., 2010; Benito-Calvo et al., 2011).

Bones subjected to trampling can present striae over the entire surface. It is important to characterize these striae and differentiate them from cut marks generated during hominin butchering tasks in order to make valid subsequent interpretations (Behrensmeyer et al., 1986; Domínguez-Rodrigo et al., 2009).

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Macroscopically, trampling tends to present features that allow them to be differentiated from other striae (Andrews and Cook, 1985; Behrensmeyer et al., 1986; Olsen and Shipman, 1988; Domínguez-Rodrigo et al., 2009). According to Olsen and Shipman (1988), modifications caused by trampling are characterized by a U-shaped section, the absence of a location and distribution pattern, and a thin, shallow stroke lacking internal microstriation. However, current works seem to disagree with this description in some aspects. Domínguez-Rodrigo et al. (2009) determined that trampling striae also tend to present internal microstriation.

Behrensmeyer et al. (1986) also highlighted the variability of trampling marks, mainly because second striae can give rise to new abrasions capable of destroying the original morphology of marks and their internal microstriations. They suggest that a cut mark subjected to trampling could become indistinguishable from a trampling mark alone, as Oliver (1984) suggested previously. This process can occur in just a few minutes, as also indicated by Shipman and Rose (1983) and Bromage (1984). Factors such as sedimentary context, angularity of the larger particles and trampling intensity also influence the degree to which these marks appear (Olsen and Shipman, 1988).

The problem appears when bone surfaces have been altered and the diagnostic criteria that characterize the two types of striae (trampling and cut marks) have disappeared or been altered.

Some works have described the effects of diagenesis on bone surfaces. Effects of lichens, algae and fungi over bones surfaces have been well synthetized (Fernándeez-Jalvo, 1992; Fernández-Jalvo et al., 2002). Fungi are the most studied organic agent causative of chemical alterations. Piepenbrink's studies (1989) showed their ability for dissolve or break down bone tissue. Fungi capacity for produce perforations on bones have also been displayed (Marchifava et al., 1974).

Root-etching effects on bone surfaces have also been described (Behrensmeyer, 1978), although Fernándeez-Jalvo (1992) has defended fungi (*Mycorrhizae*) and bacteria (*Rhizobium*) action as causative of root-etching modification. Roots may overlap, create new striae and remove previous striae (Andrews and Cook, 1985; Andrews, 1990).

Most experimental works have elaborated diagnoses using rather static frameworks, in which single-agent processes have been modeled independently and the resulting morphologies and diagnostic criteria have been used as if they were static byproducts. For this reason, some authors have suggested marks interpretation should be limited to well-preserved bone surfaces or portions of those assemblages where bone preservation maintains the original properties of the cortical surface (Domínguez-Rodrigo et al., 2010). In point of fact, marks modification is the result of multiple-process agents (Behrensmeyer et al., 1986). Marks metamorphoses through dynamic biostratinomic processes have recently been further championed by Gaudzinski-Windheuser et al. (2010).

Bones in contact with sediments below pH 4 can also be corroded (Andrews, 1990), on the ground and after burial (Fernández-Jalvo et al., 2002). Highly alkaline sediments may also corrode bone tissue during fossilization process (Fernández-Jalvo et al., 2002). Effects of soil chemistry is reflected as a corrosion located on bones portions that have in contact with sediments, although bones may roll and change their position, producing the corrosion of all bone surface (Fernándeez-Jalvo, 1992).

The chemical alteration of bones, usually caused by rinsing soluble sediments, is common in many assemblages. A high level of lixiviation leads to the greater alteration of surfaces and, consequently, a high alteration of superficial marks. This type of alteration was documented in the faunal remains of the ~ million-years-old Barranc de la Boella site, the surfaces of which have been heavily chemically modified and superficial marks are altered and, in some cases, undistinguishable.

Correct diagnosis of hominin activities by analyses of bone remains during the Lower Pleistocene is important to realized correct inferences about the role of hominins in these ancient chronologies. These studies required an accurate investigation of taphonomic process. Domínguez-Rodrigo et al. (2010) have shown as a cut mark misidentification produce wrong inferences about the behavior of the first hominins (McPherron et al., 2010).

The aim of this paper is to analyze chemically altered trampling and cut marks, and document the lost and preserved diagnostic criteria which can be used to differentiate between the two. Our results were applied during the analysis of the chemically altered superficial marks located on the remains recovered at the La Mina site (Barranc de la Boella). Although these marks present features similar to those expected in cases of trampling, some of those features seem to be related to cut marks. The correct identification of these marks is necessary in order to conduct valid future zooarchaeological and taphonomical studies (*in prep.*).

2. The Barranc de la Boella site

The Barranc de la Boella site is located in the north-eastern corner of the Iberian Peninsula, in the township of la Canonja (Tarragona, Spain) (Fig. 1). The gully has been a recognized archaeological and paleontological site since the first third of the twentieth century (Bataller, 1935). However, it was not until the seventies that Dr. Salvador Vilaseca discovered the paleontological potential of the site with the discovery of *Elephas meridionalis* remains (Vilaseca, 1973).

The Barranc de la Boella is an outdoor archaeopaleontological site whose formation is related to a deltaic sedimentary environment. Six lithostratigraphic units have been identified at 9 m thick sedimentary succession, fully described in Vallverdú et al. (2014). Lithostratigraphic unit II is the richest in remains. Unit II contains poorly stratified sand and gravel with a total thickness of 2 m (Vallverdú et al., 2014). Early studies dated this level at the Lower-Middle Pleistocene transition (0.78 Ma) (Saladié et al., 2008; Vallverdú et al., 2008). Recently, Lozano-Fernández et al. (2013) have suggested a chronology of less than a million years for these levels, based on the study of the micromammal remains recovered. Recent paleomagnetic and cosmogenic nucleides analysis confirms this hypothesis, suggesting a 0.96–0.78 Ma chronology for the unit II (Vallverdú et al., 2014).

Scheduled excavation began in the gully in 2007 at three different archaeological sites (Cata 1, El Forn and La Mina), although the actual work at the La Mina site started in 2008. Three archaeopaleontological levels have been differentiated at La Mina unit II, with over 900 faunal, coprolite and stone tool remains recovered. The paleoecological diversity of the assemblage seems to be typical of a landscape near ponds. *Cervus elaphus* is the most highly represented taxa, although *Dama* cf. *vallonetensis* and *Megaloceros* have been documented as well. Remains of *Equus* cf. *stenonis*, *Hippopotamus antiquus* and *Mammuthus meridionalis* have also been found. Among the carnivores, remains of *Ursus sp.*, *Canis mosbachensis* and a medium-sized felid have been recovered, in addition to coprolites belonging to a hyenid. Further studies have being carried out currently.

3. Material and methods

Both archaeological and experimental remains were then analyzed using a binocular microscope (OPTECH HZ) at 60 increases. The cut marks were analyzed in accordance with the criteria established by Domínguez-Rodrigo et al. (2009). The

Fig. 1. Location of the Barranc de la Boella site in relation to western Europe (top, left) and the northeastern Iberian peninsula (top, center). Distribution of the different archaeological sites in the gully (right) and a view of the La Mina site (bottom).

trampling marks were analyzed and documented using the criteria established by Domínguez-Rodrigo et al. (2009) and other previous studies (Shipman and Rose, 1983; Oliver, 1984; Bromage, 1984; Andrews and Cook, 1985; Behrensmeyer et al., 1986; Olsen and Shipman, 1988; Fiorillo, 1991).

After experimentation process, the free software Paleontological Statistics (PAST) (Hammer et al., 2001) was used and a correspondence analysis was conducted in order to compare the data presented by Domínguez-Rodrigo et al. (2009) with the results of our study.

All processes were recorded using a Sony Cyber-shot DSC-R1 digital camera. Detailed photos were also taken the USB Digital Microscope DigiMicro scale 2.0, and an environmental scanning electron microscope (ESEM, FEI Quanta 600) was used to take photos and analyze striae in detail.

3.1. Archaeological material

A total of 691 remains have been recovered and analyzed from the La Mina site. Animals from different body weigh are represented, although medium (100−300 kg) (38.2%) and large-sized

(300−1000 kg) (16.6%) carcass are the most represented. The anatomical representation shows a high variability. All skeletal parts are represented in the La Mina assemblage, although the shafts of large bones are the most preserved.

Both biostratinomic and diagenetic modifications were documented during the analysis of faunal remains. The analysis of trampling and unidentifiable marks included the location, distribution and microscopic features of every striae.

3.2. Experimental material

Four fresh large bones belonging to an adult *Bos taurus* (a humerus, a tibia and two femurae) were used in the experiment. Previous to the start of the experiment, the surfaces of the bones were analyzed and all marks were documented.

The first step was to reproduce the cut marks (Fig. 2A). All cut marks were made using a simple flint flake. These marks does not reproduce butchery marks because the presence and distribution of such marks can be distinct from the random pattering produced by taphonomic processes although the characteristics of any incision made are the same. Eleven marks were made on the shaft of the

Fig. 2. Different phases of the experimental series: reproduction of the cut marks (A) and partial burial of bones in plastic mesh for reproduce the effects of trampling at the Boella gully (B).

humerus: six on the anterior face and five on the posterior face. A total of fourteen marks were made on the tibia: four on the shaft of the anterior face, seven on the shaft of the posterior face and three on the crest of the medial face. Finally, thirteen marks were made on the shaft of one of the femurs: seven on the anterior face and six on the posterior face.

In all cases, the cut marks on the anterior surface of the shaft were made from the lateral side to the medial and from proximal to distal. The marks on the posterior face were always made from the medial face to the lateral side and from the proximal to the distal area. The marks on the tibia were made from the posterior face to the anterior and from the proximal to the distal area.

Generally, posterior to making the cut marks, the bones were fragmented using direct percussion with two granite hammers (with a smooth and rounded surface) on a limestone anvil (with a smooth and angled surface). With the second femur, however, the order of the process was inverted. The shaft was first fragmented with a radial into eight parts and afterward four cut marks were made on each part. This process allowed us to study the shaft, as many previously made marks were lost during the fracturing process. Next, all the remains were boiled in water for 30 min, washed by hand, and left to dry at room temperature.

The cut marks were analyzed in accordance with the criteria established by Domínguez-Rodrigo et al. (2009). However, the trajectory and orientation of the grooves were not taken into account in the experimental project, because the marks were not made during carcass processing. All cut marks were identified as incisions, defined as thin striae of variable dimensions, made in a continuous movement in the same direction as the longitudinal axis of the tool edge (Binford, 1981; Potts and Shipman, 1981).

After the cut mark analysis, the bones were buried for 34 days (25 December 2013—28 January 2014) at the Boella gully to reproduce trampling at sandy sediment with gravels, in an area where water currents are abundant. Bones were placed inside a mesh to avoid dispersal and subsequently covered with some sediment, which did not cover the mesh completely (Fig. 2B). When water currents occur, a friction process between bone and sandy particles and gravels is produced, reproducing trampling successfully.

After this process, the bones were removed and cleaned with water and left to dry at room temperature. Trampling marks were analyzed and documented using the criteria mentioned previously. Location and distribution of both trampling and cut marks were documented and photographed after each process, in order to differentiate both marks when were located at same bone specimen.

The last step was the chemical alteration of the remains. They were immersed in a solution of 5% hydrochloric acid with water, in
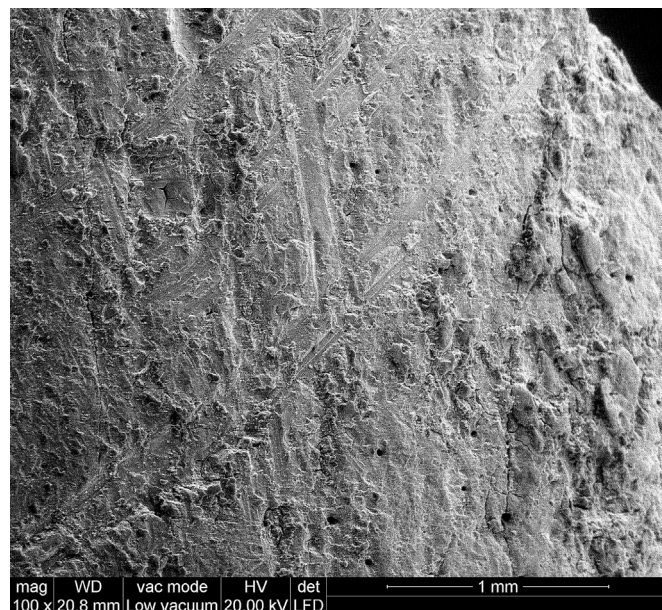

Fig. 4. Unidentified marks located on the surface of a long bone of a medium-sized carcass at the La Mina site. Photo taken with an environmental scanning electron microscope (ESEM).

two phases of 10 s each. This low combination (acid concentration and time) was selected because it allowed us to control the progress of the alteration. This low solution caused a slight alteration of the surfaces. As a result, the experimentally reproduced striae presented similar grades of damage to the striae located at the Barranc de la Boella site.

At the first phase, all the experimental bones with both trampling and cut marks were immersed in the solution. After the immersion, the remains were analyzed and the changes in the marks were documented. Silicone molds were also made before each change using silicone in two components (Provil Novo). After this process, bones that still exhibited striae over the surface were immersed another time. Changes in the marks were also documented after the second phase of chemical alteration.

4. Results

4.1. Archaeological material

Sixteen unidentified marks were documented on five different bones: deer's jaw, femur (Fig. 3) and metatarsus, a long bone of a medium-sized animal and a rib of a very large animal. The marks

Fig. 3. Deer's femur from La Mina site. Two unidentifiable incisions are documented on the shaft.

are all superficial except one, which has a relatively greater depth. The marks tend to occur in parallel or sub-parallel to each other, with a U-shaped morphology and lacking (in most cases) internal microstriation. Other features (flaking, the shoulder effect, micro-abrasion, etc.) are also absent (Fig. 4).

On the other hand, 53 trampling striae have also been documented, distributed in 17 remains. Trampling tends to appear on different skeletal parts and body-sized categories. Generally appears as superficial striae, although one notch has also been documented. These marks have well preserved and properly identified.

All La Mina surface striae were analyzed following the criteria established by Domínguez-Rodrigo et al. (2009) (Table 1).

4.2. Experimental material

A total of 66 bone fragments were obtained. Seventy-one incisions were identified, distributed over 28 remains (42.4%) (Fig. 5).

Sixty-four trampling-marks were identified on 26 remains (39.4%). The analysis of the cut and trampling marks was realized (after each phase) according to the criteria mentioned previously (Table 2).

In general, the experimental cut marks were characterized by a V-shaped cross-section, symmetrical walls (87.3%), and by the absence of barbs (73.2%) and the shoulder effect (84.5%). Flaking was present in 47.9% of the remains. Internal microstriation was documented in 45.1% of the cut marks. This consisted, in most cases, of continuous, straight striae on the walls of the groove. Furthermore, the experimental trampling marks were characterized by a tendency towards symmetry (78.1%) and by the absence of flacking (79.7%), barbs (95.3%) and the shoulder effect (100%). The morphology of the cross-sections was varied and only one mark (3.1%) had internal microstriation.

After being immersed in hydrochloric acid, most of the diagnostic features that had been previously identified were lost or altered, both in the trampling marks and cut marks (Fig. 6). After the first immersion in hydrochloric acid, the most superficial marks

Table 1
Criteria established by Domínguez-Rodrigo et al. (2009) for identifying and analyzing trampling and cut marks (columns 1–3) were used in the analysis of the La Mina surface striae (columns 4–5). Absolute and (percentage) data are presented.

Features		Trampling (Domínguez-Rodrigo et al., 2009)	Unretouched tool cut marks (Domínguez-Rodrigo et al., 2009)	Retouched tool cut marks (Domínguez-Rodrigo et al., 2009)	Trampling Boella site	Unidentified -marks Boella site
Groove trajectory						
1	Straight	75 (29.8)	230 (93.5)	102 (97.1)	45 (84.9)	18 (100)
2	Curvy	42 (16.7)	16 (6.5)	0 (0)	5 (9.4)	0 (0)
3	Sinuous	134 (53.4)	0 (0)	3 (2.9)	3 (5.7)	0 (0)
Barb						
4	Present	6 (2.4)	25 (10.2)	6 (5.7)	1 (1.9)	0 (0)
5	Absent	245 (97.6)	221 (89.8)	99 (94.3)	52 (88.1)	18 (100)
Mark orientation						
6	Parallel	25 (9.9)	1 (0.4)	0 (0)	0 (0)	6 (33.3)
7	Perpendicular	20 (8)	96 (39)	3 (2.9)	13 (20.8)	2 (11.1)
8	Oblique	206 (82.1)	149 (60.6)	102 (97.1)	40 (79.2)	10 (55.6)
Groove shape						
9	"V"	10 (4)	238 (96.7)	6 (5.7)	32 (60.4)	6 (33.3)
10	"U"	241 (96)	8 (3.3)	99 (94.3)	21 (39.6)	12 (66.7)
Symmetry						
11	Symmetrical	226 (90)	212 (86.2)	42 (40)	49 (92.5)	16 (88.9)
12	Asymmetrical	25 (9.9)	34 (13.8)	63 (60)	4 (7.5)	2 (11.1)
Shoulder effect						
13	Present	15 (5.9)	81 (32.9)	78 (74.3)	2 (3.8)	2 (11.1)
14	Absent	236 (94.1)	165 (67.1)	27 (25.7)	51 (96.2)	16 (88.9)
Flacking on shoulder						
15	Present	7 (2.7)	36 (14.6)	54 (51.4)	3 (5.7)	3 (11.7)
16	Absent	244 (97.3)	210 (85.4)	51 (48.6)	50 (94.3)	15 (88.3)
Extent of flacking						
17	Long	2 (0.7)	0 (0)	12 (11.4)	0 (0)	0 (0)
18	Short	5 (1.9)	36 (14.6)	42 (40)	3 (5.7)	3 (11.7)
19	Absent	244 (97.2)	0 (0)	51 (48.6)	50 (94.3)	15 (88.3)
Overlapping striae						
20	Present	203 (80.3)	12 (4.9)	0 (0)	18 (34)	11 (61.1)
21	Absent	48 (19.7)	234 (95.1)	105 (100)	35 (66)	7 (38.9)
Internal microstriation						
22	Present	188 (75)	190 (77.2)	105 (100)	2 (3.8)	0 (0)
23	Absent	63 (25)	56 (22.8)	0 (0)	51 (96.2)	18 (100)
Microstriation trajectory						
24	Continuous	169 (67.3)	190 (100)	105 (100)	2 (100)	–
25	Discontinuous	82 (37.2)	0 (0)	0 (0)	0 (0)	–
Shape microstriations trajectory						
26	Straight	140 (82.8)	190 (100)	105 (100)	2 (100)	–
27	Irregular	29 (17.2)	0 (0)	0 (0)	0 (0)	–
Location of microstriations						
28	Walls	7 (2.9)	180 (94.7)	3 (2.9)	1 (50)	–
29	Bottom	219 (87.1)	0 (0)	93 (88.6)	0 (0)	–
30	Both	25 (10)	10 (5.3)	9 (8.6)	1 (50)	–
Microabrasion						
31	Absent	1 (0.4)	6 (2.4)	0 (0)	0 (0)	0 (0)
32	Present	250 (99.6)	240 (97.6)	105 (100)	53 (100)	18 (100)
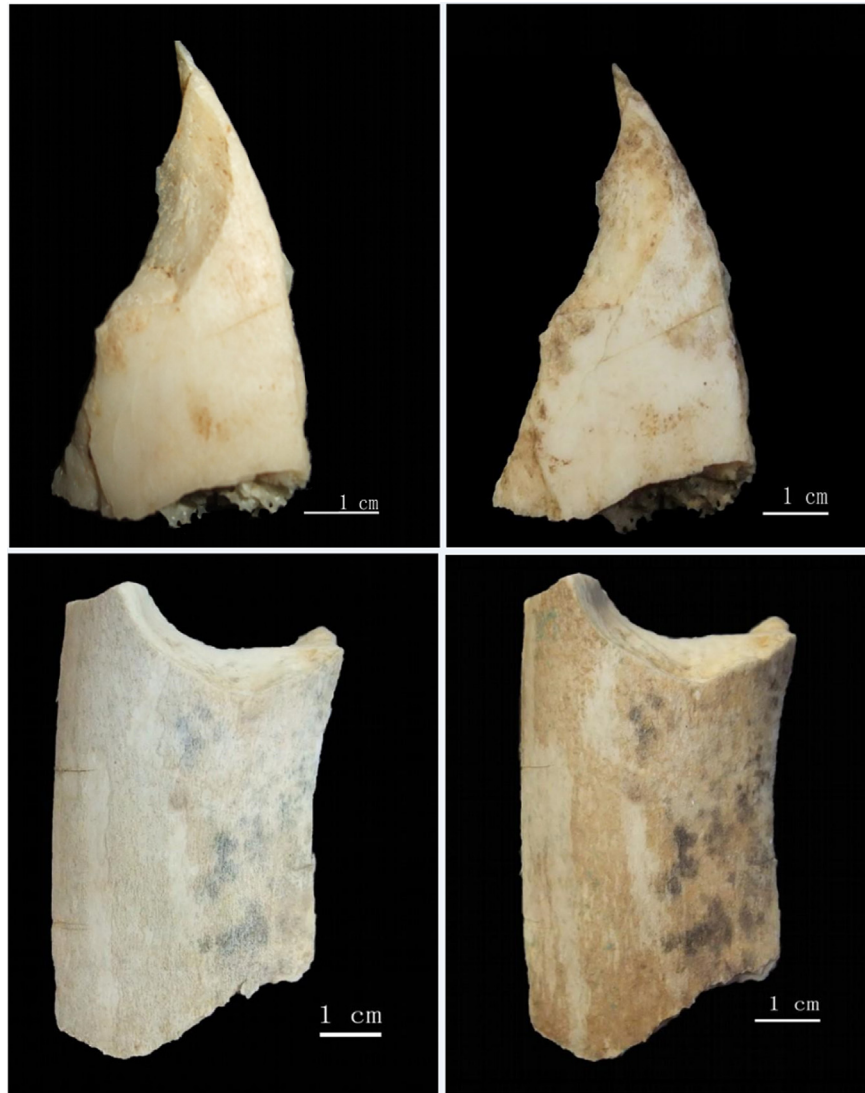
Fig. 5. Two experimental bones before (left) and after (right) the chemical alteration process. Alteration of the surfaces is detectable macroscopically.

disappeared (36% of trampling and 2.8% of the cut marks). Among the cut marks, the most significant alteration was the loss of internal microstriation in 87.5% of the marks and the increase in flaking by 26.6%. The disappearance of the microabrasion, a decrease in the presence of barbs and a slight increase in the asymmetry of the marks was also documented. Among the trampling marks, a remarkable increase in flaking was documented after the initial chemical treatment (246.2%), from 20.3% of flacking prior alteration to 62.3% after the first phase of alteration.

After the second immersion, a loss of cortical tissue was noted in the remains. As a result, a marked lack of features such as flaking, the shoulder effect and barbs was documented. Furthermore, internal microstriation was lost in both trampling marks and cut marks (Fig. 7). All marks were completely altered and an increase in the porosity of the bone surface (Fig. 8) was detected.

In sum, after chemical alteration, most of the criteria established in previous works (Shipman and Rose, 1983; Oliver, 1984; Bromage, 1984; Andrews and Cook, 1985; Behrensmeyer et al., 1986; Olsen and Shipman, 1988; Fiorillo, 1991; Domínguez-Rodrigo et al., 2009) for distinguishing between evidence of trampling and cut marks have been lost or modified when chemical alteration occurs.

For this reason, these criteria should be used in assemblages (or part of assemblages) with optimal preservation, but not when chemical modification is detected. They should be dropped, though, when chemical modification is detected.

5. Discussion

The chemical alteration generally caused by the lixiviation of sediments affects bone remains and is present in many archaeological sites. This type of alteration is documented in the faunal remains of the Barranc de la Boella site, altering different striae located on the surface of the bones and hindering their correct identification. The validity of future zooarchaeological and taphonomical studies will depend on a clear understanding of how different marks respond to chemical alteration.

In this paper, trampling marks and cut marks were subjected to chemical alteration. An analysis of those marks allowed us to identify the diagnostic criteria that are lost, the elements that are preserved and, in this case, the degree to which the marks are modified after exposure to certain chemical processes.

Table 2
Analysis and comparison of the experimental trampling and cut marks in the different phases of alteration, in accordance with the criteria established by Domínguez-Rodrigo et al. (2009). Groove trajectory and mark orientation are not established because these parameters were not measurable in the experimental work. Absolute and (percentage) data are presented.

	Feature	Phase 0		Phase 1		Phase 2	
		Experimental trampling	Experimental cut marks	Experimental trampling	Experimental cut marks	Experimental trampling	Experimental cut marks
	Number of marks	64	71	41	69	40	67
Barb							
4	Present	3 (4.7)	19 (26.8)	2 (4.9)	11 (15.9)	1 (2.5)	1 (1.5)
5	Absent	61 (95.3)	52 (73.2)	39 (95.1)	58 (84.1)	39 (97.5)	66 (98.5)
Groove shape							
9	"V"	30 (46.9)	62 (87.3)	20 (48.8)	60 (87)	20 (50)	59 (88.1)
10	"U"	34 (53.1)	9 (12.7)	21 (51.2)	9 (13)	20 (50)	8 (11.9)
Symmetry							
11	Symmetrical	50 (78.1)	62 (87.3)	24 (58.5)	54 (78.3)	24 (60)	53 (79.1)
12	Asymmetrical	14 (21.9)	9 (12.7)	17 (41.5)	15 (21.7)	16 (40)	14 (20.9)
Shoulder effect							
13	Present	0 (0)	11 (15.5)	0 (0)	9 (13)	0 (0)	8 (11.9)
14	Absent	64 (100)	60 (84.5)	41 (100)	60 (87)	40 (100)	59 (88.1)
Flacking on shoulder							
15	Present	13 (20.3)	34 (47.9)	32 (78)	43 (62.3)	6 (15)	21 (31.3)
16	Absent	51 (79.7)	37 (52.1)	9 (22)	26 (37.7)	34 (85)	46 (68.7)
Extent of flacking							
17	Long	1 (0.9)	0 (0)	16 (39)	16 (23.2)	1 (2.5)	2 (3)
18	Short	12 (18.8)	34 (47.9)	16 (39)	27 (39.1)	5 (12.5)	19 (28.4)
19	Absent	51 (79.7)	37 (52.1)	9 (22)	26 (37.7)	34 (85)	46 (68.7)
Overlapping of striae							
20	Present	17 (26.6)	9 (12.7)	11 (26.8)	9 (13)	10 (25)	8 (11.9)
21	Absent	47 (73.4)	62 (87.3)	30 (73.2)	60 (87)	30 (75)	59 (88.1)
Internal microstriation							
22	Present	1 (1.6)	32 (45.1)	1 (2.4)	4 (5.8)	0 (0)	0 (0)
23	Absent	63 (98.4)	39 (54.9)	40 (97.6)	65 (94.2)	40 (100)	67 (100)
Trajectory of microstriation							
24	Continuous	1 (100)	26 (81.3)	1 (100)	1 (25)	–	–
25	Discontinuous	0 (0)	6 (18.7)	0 (0)	3 (75)	–	–
Shape microstriation trajectory							
26	Straight	1 (100)	31 (96.9)	1	4 (100)	–	–
27	Irregular	0 (0)	1 (3.1)	0	0 (0)	–	–
Location of microstriations							
28	Walls	1 (100)	30 (93.8)	1 (100)	4 (200)	–	–
29	Bottom	0 (0)	0 (0)	0 (0)	0 (0)	–	–
30	Both	0 (0)	2 (6.2)	0 (0)	0 (0)	–	–
Microabrasion							
31	Absent	61 (95.3)	71 (100)	41 (100)	69 (100)	40 (100)	67 (100)
32	Present	3 (4.7)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

In general, the trampling reproduced experimental results in the most superficial striae, causing the disappearance of 36% of the cut marks in the first phase of alteration. Although some studies have argued that the trampling tends to occur more superficially (Olsen and Shipman, 1988), the fact is that the depth of the cut marks mainly depends on the force exerted by the tool at the time contact occurs (Bello and Soligo, 2008). In this work, the most superficial cut marks also disappeared after the first phase of alteration.

Many of the features established by Domínguez-Rodrigo et al. (2009) as a means of differentiating between the two types of marks (internal microstriation, microabrasion, the shoulder effect, etc.) decreased quantitatively after the first phase of experimentation, and disappeared completely (or almost completely) after the second phase. The highest degree of variation was noted in the amount of flaking documented in the two mark types. After the first phase, flaking increased in both types of marks and tended to extend only short distances. Conversely, it decreased after the second phase, especially on the trampling marks. This is because the acid attacks the outer bone layers (eternal circumferential system), causing an initial alteration of these layers, and thus increasing the frequency of flaking. After the second immersion, these layers eventually either partially or completely disappear, thus causing part of the flaking to disappear as well.

Prior to the chemical alteration phase, the experimental cut marks were similar to the cut marks described by Domínguez-Rodrigo et al. (2009), based on the presence of internal microstriation (mainly regular, continuous and localized on the walls), the presence of the shoulder effect and in the limited effect of microabrasion. The trampling defined by Domínguez-Rodrigo et al. (2009) featured a morphology characterized by a U-shaped cross-section, overlapping striae and irregular, discontinuous microstriation at the base of the groove.

Correspondence analysis (Fig. 9) showed a clear grouping among the chemically altered remains (including archaeological remains), and this grouping was far more significant than that of the remains that had not been altered.

In addition, correspondence analysis also suggests a direct statistical relationship between the marks documented on the archaeological remains of the Boella site, all the chemically altered experimental marks, and the trampled marks in the stage prior to chemical alteration. The absence of microabrasion, internal microstriation and the shoulder effect and the presence of extended flaking are correlating features among these different marks.

The data suggest that trampling and cut marks progressively lose the characteristic elements that define and differentiate them
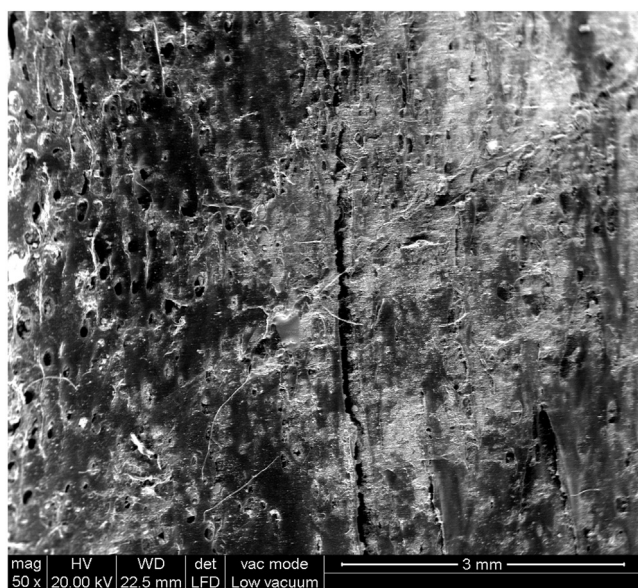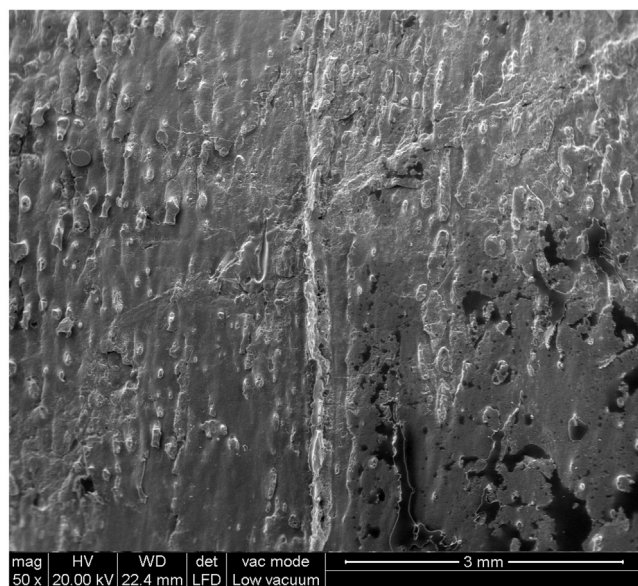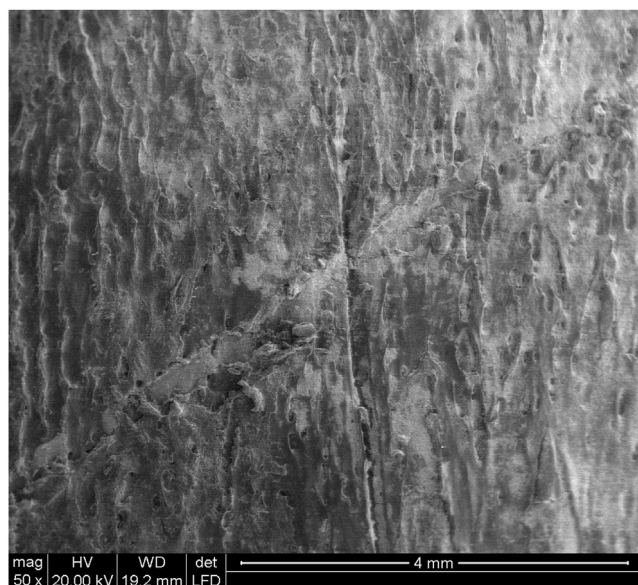
when affected by chemical alteration. Statistically, the differences are slight. The morphology of the cross-section (Potts and Shipman, 1981) seems to be one of the features that is least affected by chemical alteration. However, this feature cannot be used to differentiate between the types of marks, because trampling marks can appear as having either a V-shape or a U-shape, as found in the data presented by Domínguez-Rodrigo et al. (2009) and in this work. Also, the symmetry of the walls seems to be little affected by chemical alteration. However, Bello and Soligo (2008) noted that the symmetry of the cut marks depends on the inclination of the tool (in relation to the bone surface) at the time contact occurs, so both morphologies are relevant. Chemical alteration ultimately produces highly altered grooves, hindering the correct identification of mark type.

All these criteria have been considered in the analysis of different types of marks on a selection of skeletal remains from the Boella site. The marks analyzed did not present features that allowed the designation of anthropic or mechanical origin, even when considering the possible morphological variations related to the chemical alteration of the bone surface established within this experiment. Diagnostic criteria have not been documented on marks located at the archaeological material, as occurs at experimental marks chemically altered, becoming impossible their correct identification. Thus, this research support Domínguez-Rodrigo et al. (2010) suggestion that just well-preserved bone surfaces striae should be take into account to diagnosing hominin activities. Undistinguishable marks located at La Mina site may not be included in future zooarchaeological and taphonomical studies, as their designation as cut marks may lead to erroneous inferences (Behrensmeyer et al., 1986) about the behavior of one of the earliest groups of hominins that inhabited the Iberian Peninsula. The development of subsequent experimental work will more precisely clarify the origin of these marks.

6. Conclusions

In this study, trampling and cut marks were reproduced and subjected to chemical alteration. The analysis documented how these marks respond to alteration and showed that in both types of mark much of the diagnostic criteria that would allow researchers to distinguish between them was lost and/or modified after chemical alteration.

In general, marks tend to preserve the symmetry and the shape of the cross-section after alteration. However, features as microstriation, barbs and the shoulder effect tend to gradually disappear as the modifying process progresses. These results suggest that zooarchaeological inferences based on cut marks analysis should be made on well-preserved bones surfaces only.

The application of these results to marks located on five bone remains from the La Mina site (Barranc de la Boella) suggests that the diagnostic elements are modified to such a degree as to greatly hinder the correct identification of mark type subsequent to chemical alteration. Therefore, these marks cannot be taken into account in zooarchaeological and taphonomical studies, as they may lead to misinterpretations of the behavior of these hominin groups.

Fig. 6. A cut mark (lengthwise) and a trampling mark (oblique) at three different phases of the experiment: before chemical alteration (top), after the first phase (center) and after the second phase (bottom). Photos after the first alteration were taken from a mold. The negative image has been digitally inverted. Photos were taken with an environmental scanning electron microscope (ESEM).
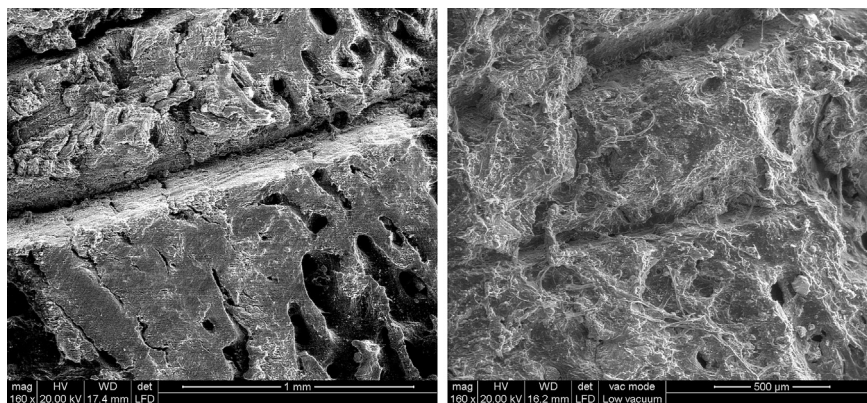
Fig. 7. Cut marks at the beginning (left) and end (right) of the experimental process. Internal microstriations and microabrasion were lost after chemical alteration. Photos were taken with an environmental scanning electron microscope (ESEM).
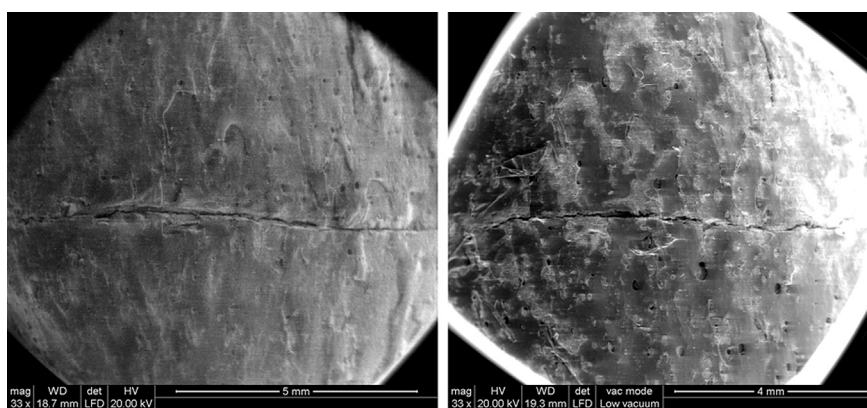
Fig. 8. A cut mark at the beginning (left) and end (right) of the experimental process. The second image shows the alteration to the cut mark and the increase in porosity of the bone surface. Photos were taken with an environmental scanning electron microscope (ESEM).
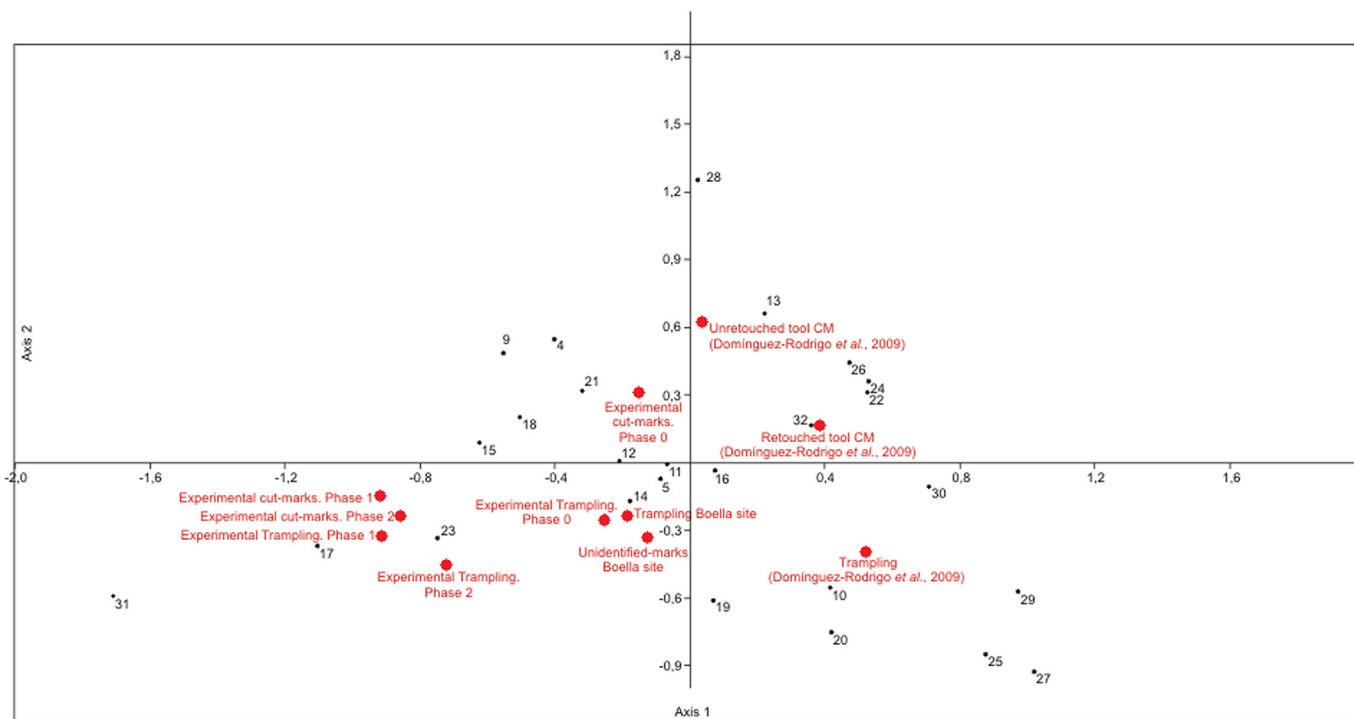
Fig. 9. Correspondence analysis in which data presented by Domínguez-Rodrigo et al. (2009) were combined with experimental and archaeological data. The trajectory and orientation of the grooves were not taken into account.

Acknowledgments

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